MAKING VENTILATION-PRESSURE SURVEYS WITH ALTIMETERS

BY G. E. MCELROY AND D. S. KINGERY

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G. E. McElroy[1/] and D. S. Kingery[2/]

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SUMMARY

Ventilation-pressure surveys are required to determine the rates of pressure losses in various parts of mine-airway systems. These may be determined directly by differential pressure measurements or deduced from absolute pressure measurements. Despite the confusion caused by its inverted nonlinear scale, the altimeter has special application to pressure surveys in mines in which only small differences in elevation are involved, as is true for most of our large bituminous-coal mines. In these, the judicious use of information obtained by pressure surveying can result in greatly improved working conditions as regards health and safety and, in many instances, can yield large financial returns.

The main purposes of this report are to discuss methods of using altimeters for pressure surveys and to present the particular methods of making surveys and calculating the results of surveys used by the Mine Ventilation Section of the Bureau of Mines.

INTRODUCTION

In order to plan improvements in mine-ventilation systems according to engineering practice rather than by the trial-and-error methods in common use, complete information must be available on the quantities flowing in various parts of the system and on the rates at which pressures produced by fans and natural drafts are used up on the major airways. Quantities and pressure differences together determine where the horsepower applied to the system is used and where changes can be made economically.

Methods of making quantity surveys accurate enough for engineering estimates are well known and will not be discussed herein. Determining pressure gradients for mine-airway circuits is a more difficult procedure and one that has had only limited application. Theoretically, pressure drops for the component parts may be calculated from the physical conditions and dimensions of the airways and a knowledge of experimentally determined friction factors. Practically, although theory can give approximations for projected openings, the physical conditions and dimensions of actual workings are so variable as to require direct determinations of pressure differences for useful applications.

The material presented in this report is based on a continuing interest in the possibility of determining pressure losses in mine-ventilation systems by absolute-pressure methods that dates back to the early twenties. Sporadic attempts at limited surveys at that time gave somewhat negative results. More complete surveys by Bureau engineers in the mid-thirties were reported to have yielded fair results, but no records exist.

Early British experiences were reported (1)[3/] by E. I. David and A. L. Davies in 1928. Early experiences in the United States were reported (2) by J. A. Saxe, then chief engineer of the Ellsworth Collieries, in 1929. A very complete report (3) on

3/ Underlined numbers in parentheses refer to items in the bibliography at the end of this report.

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air-pressure surveying was published in England in 1931 by J. N. Williamson, J. A. S. Ritson, W. E. Cooke, and I. C. F. Statham; and in 1932, J. N. Williamson published two papers (4) (5), which, along with Saxe's paper, developed considerable interest in this subject in this country. Many others have reported (6) (7) (8) the results of surveys or proposed (9) (10) survey methods.

In the later forties R. T. Artz, a Bureau engineer, made a limited number of surveys in bituminous-coal mines, following methods developed at one group of mines, with what appeared to be good results. Recalculation of his records, according to a slightl different procedure developed in 1953, showed even better results. A limited number of surveys made since that time by a number of Bureau engineers have yielded uniformly good results, although few checks of absolute accuracy have been possible.

Pressure differences may be measured directly on manometers - usually inclined for greater accuracy - connected by hose to end points of sections, or they can be deduced from absolute pressures measured at the same end points by barometers. The manometer method is quite reliable but so slow and tedious as to be properly restricted to conditions, such as deep-shaft sections and steep-pitch workings or very small pressure differences, for which barometric determinations are not sufficiently reliable, and to local determinations by U-tube manometers, or "water-gages" on doors, stoppings, and regulators.

As regards barometric instruments, only the aneroid barometer has proved portable and rugged enough for use in mine-pressure surveys, and only a few types with sufficient precision for the purpose are currently available. The Fortin or wall-type mercurial barometer is essentially a laboratory instrument of high precision. Its main use is in checking the setting of instruments used underground.

Aneroid barometers may be provided with a variety of pressure scales - even "inches of water," which would have certain advantages as regards popularizing pressure surveying, or "pounds per square foot," which would simplify calculations somewhat. The scales commonly used, particularly in "surveying" aneroids used for surface reconnaissance in determining differences of elevation, from which much of the technique of conducting underground pressure surveys developed, are "inches of mercury" and "feet of air column." The first is a direct linear pressure scale, but the latter is an inverted, nonlinear pressure scale, and instruments so scaled are termed "altimeters" rather than barometers.

SURVEY METHODS

With the precision instruments now commercially available, survey procedures are much simpler and more rapidly executed than one would infer from a survey of the literature of the subject, which, in general, is based on the use of older types of instruments and their use in comparatively deep shaft mines. And in calculating results of surveys also, the procedures required are, in general, less laborious than would be inferred from the literature.

As mine conditions are not static but continually changing and as minor changes have a greater effect on absolute-pressure measurements than on quantity measurements, speed in making pressure surveys is desirable. For comparatively large mines, pressure surveys may take 1 to 3 days, whereas the corresponding quantity surveys will take 1 to 3 weeks. It is therefore advocated that pressure surveys of large mines should be made independently of quantity surveys, which should immediately precede or follow pressure surveys.

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Whereas both types of surveys should preferably be made when the mine is idle to avoid airflow disturbances caused by moving trips and cages and by opening and closing doors, this stipulation applies particularly to pressure surveys, as the absolute pressure distribution is affected to a greater extent than the airflow, and disturbances are harder to detect because of concurrent changes in atmospheric pressure.

Because of the continual change in the absolute pressure of the atmosphere, which is reflected throughout the underground openings, it is advisable to conduct surveys at times when atmospheric pressures are comparatively steady; that is, when the rate of change is small. Conditions are roughly indicated by surface winds. Strong winds and gusts indicate rapidly changing pressures. Moreover, it is essential, of course, that fan speeds remain constant throughout a survey.

Selection of Instruments

Although almost any type of precision aneroid barometers can be used to make pressure surveys of sufficient accuracy - say, within 10 percent - to pinpoint "bottlenecks" in the ventilation system and to indicate methods of improvement, rapid surveys accurate enough to serve as a basis for economic estimates require the most precise instruments commercially available. Two instruments have been specially developed for this purpose in the United States - the Paulin (shown in fig. 1), and the Wallace & Tiernan (shown in fig. 2). Both are precision instruments of a high order. In the Wallace & Tiernan instrument movement of the pressure capsule is communicated to the pointer by the usual rack-and-pinion movement. A distinctive feature of the Paulin instrument is that the pressure capsule is brought back to a "null" position for each reading by changing the tension of a spring controlled by rotating a knob at the center of the dial, until a "tendency" pointer comes to zero position. Both instruments are made in a number of models, with different scales and ranges. For pressure surveys in shallow mines the instrument should have an altimeter scale and a range of 6,000 to 7,000 feet so that readings can be made to the nearest foot (about 0.014 inch of water); it should be supplied with a well-padded carrying case. Altimeter scales are for a theoretical column of 50° F. dry air and correspond to Smithsonian meteorological table 51. The usual range for shallow mines is -1,000 to +5,000 or 6,000 feet and the scale may be offset 1,000 feet to avoid negative readings; that is, the scale may start from 0 at the actual -1,000-foot point. Instruments can be reset and rescaled by the manufacturer to cover the same interval over a different altitude range.

Recording Instruments

For large-scale operations it would be advantageous, from the point of view of man-hours saved, to use a recording microbarograph as the base instrument. The chart of the ordinary microbarograph, however, can be read only to the nearest 0.005 inch of mercury, and such instruments are not sensitive enough for this service. The American Paulin System makes a specially sensitive microbarograph that can be read to 0.001 inch of mercury, equivalent to about 1 foot of air column; and Wallace & Tiernan, Inc., makes a photographic recording apparatus for use with its altimeters. We have had no experience in, or knowledge of, the use of these instruments.

Preliminary Planning

Before a survey is started, the ventilation map of the mine should be studied carefully, and points or stations should be provisionally selected at critical points in the distribution system, such as splits, junctions, and at major changes in the physical characteristics along main airways, at which pressure and quantity data are

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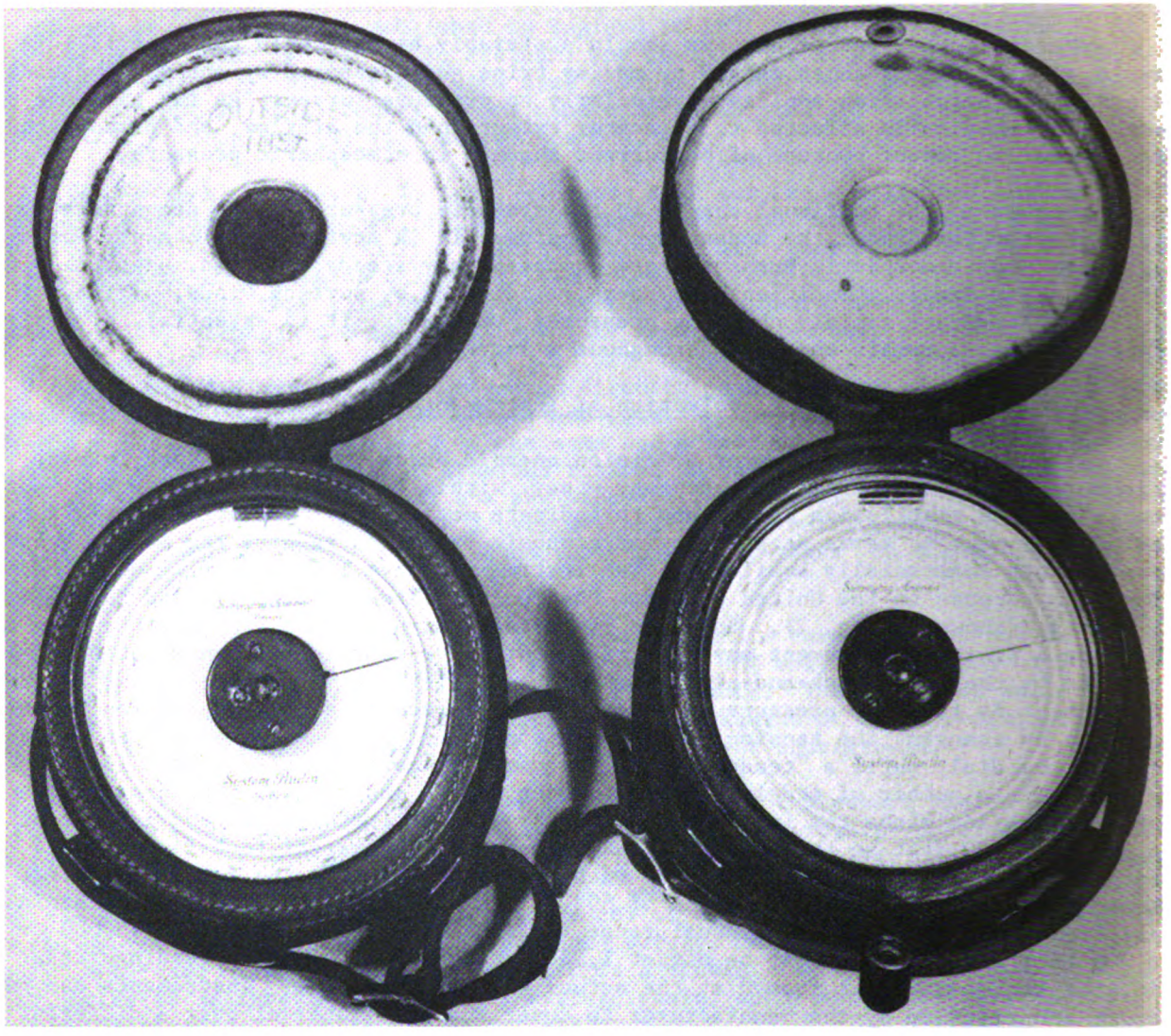

Figure 1. - Paulin altimeters in padded carrying cases.

desirable. Study of the map should be followed by a trip underground at which the exact position - usually just ahead of each split or junction - of each station should be determined and necessary data on elevations obtained. Elevations should be determined to the nearest foot if at all possible, as 1 foot of air column near sea level is equivalent to approximately 0.014 inch of water.

Survey Observations

There are two general methods of carrying out altimeter surveys, each requiring the use of two instruments. In one the altimeters are read simultaneously at each of two stations, with the observer operating at the rear station moving past his companion to the next station forward, at which similar readings are made simultaneously at a prearranged time. In the second method a base is established at which one altimeter is read at short-time intervals while readings are being taken by the other in succession at all traverse stations. The simultaneous method is the more accurate, as it avoids possible changes in air conditions as regards individual sections and obviates the necessity of correcting readings for changes in atmospheric pressure. The method,

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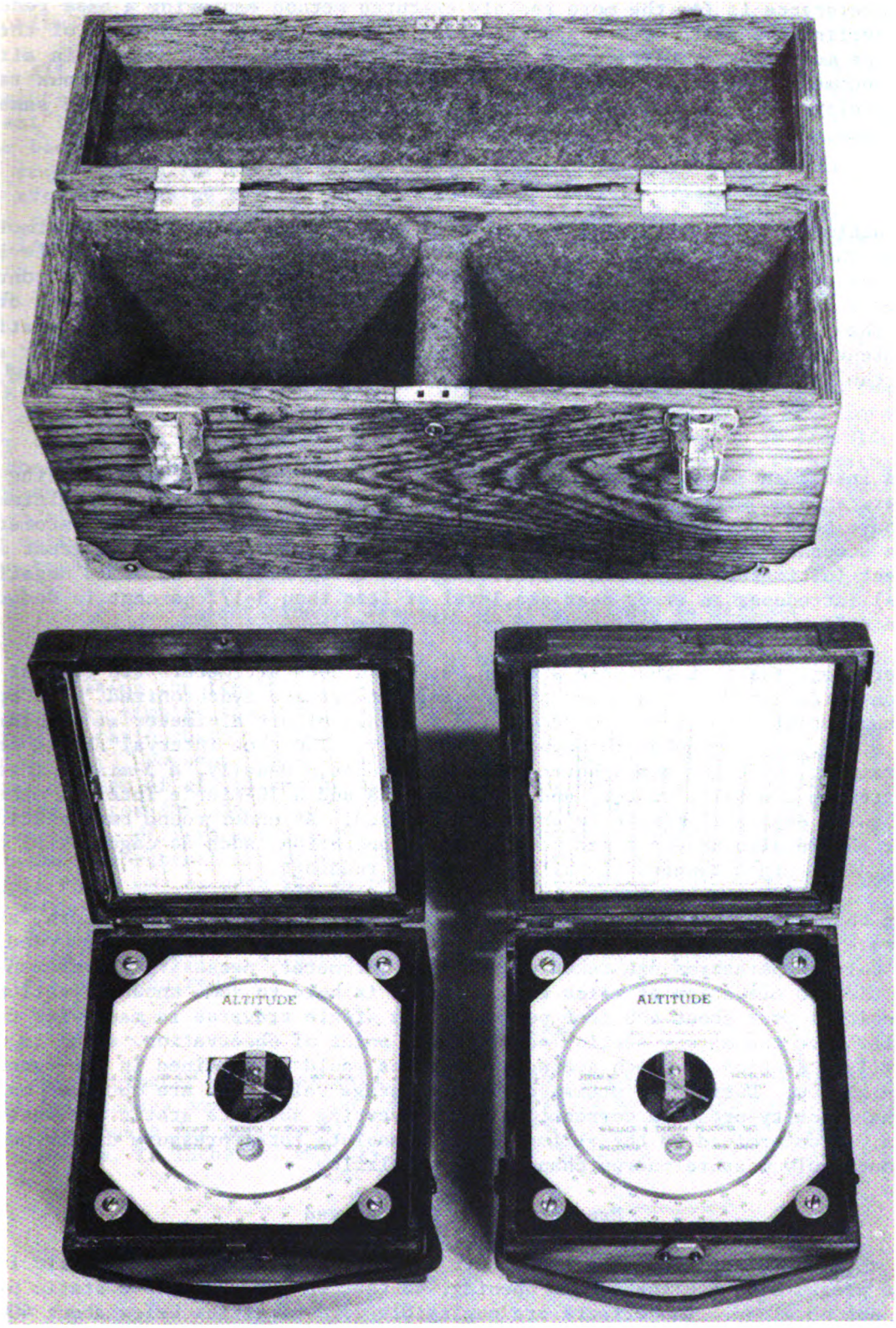

Figure 2. - Wallace & Tiernan altimeters with padded carrying case.

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however, is relatively slow unless two motors are used to transport observers, and general preference is for the more rapidly executed method employing a base recorder and a traveling observer. For shaft and slope sections, however, because of the effect of the much greater differences in elevation involved, minor changes in air conditions become more important; for these sections, the method of simultaneous readings is preferable. Calculations of pressure differences are virtually the same for both methods.

Selection of Base

As altimeter readings are affected by the normal continuous change in atmosphere pressure, the base station should be established at approximately the same elevation as the area surveyed. For drift and shallow slope and shaft mines the most convenien place for a mine survey is some point on the surface. Where the intake slope or shaf is more than 200 feet deep, however, it is desirable to establish the base station in a convenient place out of the air current near the shaft or slope bottom. For sectio surveys the base should be established at some point close to the area surveyed.

Survey Procedure

The instruments required for a survey are 2 altimeters, 2 watches, a sling psychrometer, an anemometer, a U-tube water gage, and a measuring tape. The altimeters should have been previously set by comparison with a wall-type mercurial barometer. Absolute accuracy in the setting is not too important, as a variation as great as 1,000 feet (altimeters have been deliberately set 1,000 feet off to avoid negative readings) introduces an error near sea level of less than 3-1/2 percent in deduced pressure differences.

Operations start at the base station, at which both altimeters are read at the elevation established for the base station and watches are synchronized. The operato at the base station continues to record the readings of his altimeter at regular inter vals of 5, 10, or 15 minutes throughout the survey. The time interval should be gaged by the rate at which the atmospheric pressure changes. Usually, a 5-minute interval is required in the fall, winter, and spring months and a 10-minute interval otherwise. On very quiet days a 15-minute interval can be used. At underground base stations the operator should also keep a timed record of any operation, such as cage, skip, or trip movement, that might temporarily affect the base readings.

The observer with the roving altimeter then visits each station in turn; at each two or more readings of the altimeter are made for which the times are recorded, wet-and-dry bulb temperatures are taken with the psychrometer, necessary measurements are made to tie the elevation at which the altimeter is held to some known elevation, and, for velocities over about 400 feet per minute, a single traverse is made with the anemometer over the airway section opposite the point of observation, which is not necessarily a section at which average velocities would be obtained in the concurrent quantity survey. During the pressure survey average velocities are obtained only for computing velocity-pressure corrections for converting absolute static pressure differences, as determined by the altimeters, to absolute total pressure differences that alone truly measure energy changes due to airflow.

Precautions to Be Observed

If altimeters are read in a moving air current, the pressure of the velocity exerts a pressure on the instrument opening, so that the true absolute static pressure is not obtained. The effects are negligible for velocities below about 400 feet

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per minute. The instrument should ordinarily be read at a point sheltered from direct velocity effects.

All aneroid barometers are subject to "creep" or lag in registering changes of pressures. This was quite large in older instruments but is of small moment in more recent types of high-grade instruments and is claimed to be absent in the Paulin type because of the mode of construction. References in the thirties therefore set out requirements for taking barometers underground 24 hours before starting a survey and avoiding passing through airlocks or man-doors from intake to return. Actually, time requirements for avoiding the "creep" effect can be easily determined for particular circumstances, such as traveling through shafts or slopes or passing through doors or regulator openings, by simple tests using 2 instruments, 1 at a fixed position and the other subjected to the rate and amount of pressure change involved.

Although it is desirable that the sequence of stations used in a survey circuit be taken in an orderly manner, proceeding with the air through intakes to faces and back to the starting point through returns, both speed and safety often require that the observer travel intakes between stations on returns and cross from intake to return to make his observations at points in the return airways. By traveling slowly in shafts and slopes and allowing time for pressures to equalize in passing through airlocks, the effects of "creep" are minimized. Although two or more readings are taken at a station, main reliance is placed on one taken just before moving on to the next station; thus the effects of "creep" are for the most part obviated by the time required for survey procedures.

Calculation of Pressure Differences Due to Airflow

Perhaps the greatest differences in survey procedures lie in the various methods of calculating the results of surveys. The methods in use for altimeter surveys are, in general, simpler than those used for barometer surveys, due mainly to the fact that a density-ratio chart is widely used for elevation corrections rather than a calculated air density. However, air-pressure differences due to flow are commonly determined in terms of feet of air column at mine-air density, requiring calculation of an air-density factor for use in converting to inches of water. In the method to be presented, air-pressure differences due to flow are determined in terms of feet of air column of the same theoretical air-density (50° F. dry air) as that of the altimeter scale, so a simple chart may be used for determining conversion factors. Velocity pressure for any velocity varies directly with the density of the air. An average or approximate air density usually suffices for most survey calculations because of the low velocities involved. In special instances involving high velocity, however, more accurate calculations are required.

Altimeter Scale

The altimeter scale, as said before, is an inverted, nonlinear pressure scale. This fact causes some confusion, and survey methods must usually be established on a "by rote" basis for good results. The conversion of altimeter readings to direct units of pressure, in inches of mercury, is shown in figure 3.

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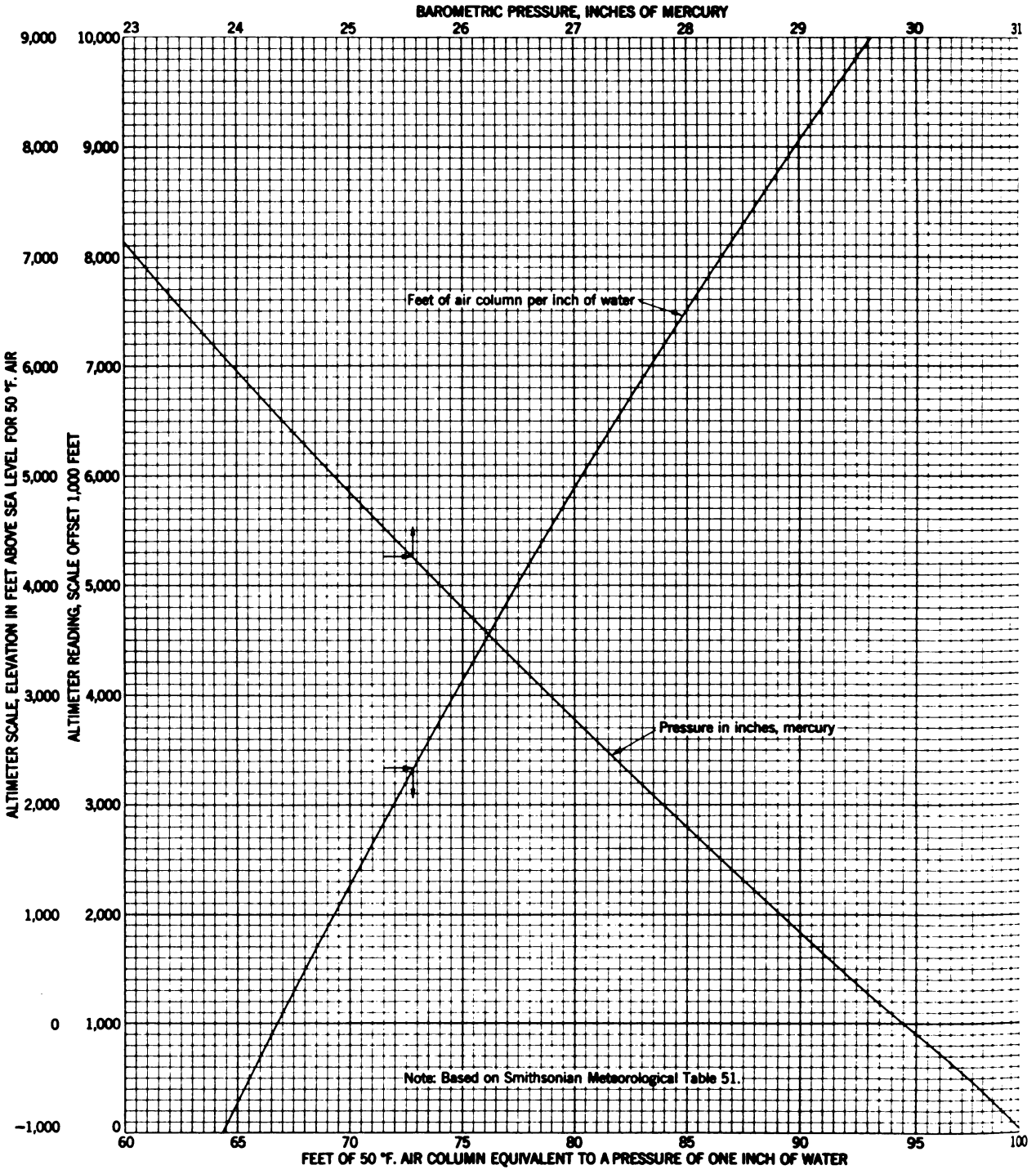

Figure 3. - Chart for converting altimeter readings to pressures, in inches of mercury, and for converting altimeter differences to equivalent pressures, in inches of water.

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Air-Density Formula

The standard formula (11) for density, or specific weight, of air is:

$$d = \frac{1.327}{460+t} \times (B - 0.378\ f); \qquad (1)$$

where

d = density, or specific weight, pound per cubic foot;

t = dry-bulb temperature, °F.;

B = atmospheric pressure, inches of mercury;

f = vapor pressure of water vapor, inches of mercury.

For unsaturated air, f is the vapor pressure at dew-point temperature, or it may be taken, in accordance with the more common practice, as the product of relative humidity, expressed as a ratio, times the f for dew-point temperature corresponding to the dry-bulb temperature. For the same wet-bulb depression, or difference between wet- and dry-bulb temperature, barometric pressure has only a very slight effect on dew-point temperatures and on relative humidities. Dew-point temperatures and relative humidities are given for various barometric pressures and wet-bulb depressions in Weather Bureau Bulletin 235 (procurable from the Superintendent of Documents, Government Printing Office, Washington, D. C., for 30 cents). Table 1, which reproduces part of the table for relative humidities at 30.0 inches barometric pressure, with a column for 0.378 f added, can be used with negligible error for altitudes within 2,000 to 3,000 feet of sea level.

Actually, for temperatures of 70° and under, there is less than 1 percent difference between dry and saturated air densitites, so the use of dry-air densities would cause no appreciable error.

Density-Ratio Chart

The density-ratio chart shown in figure 4 was, as far as is known, developed by Wallace & Tiernan, Inc. Usually, it has been used for correcting air-column differences resulting from altimeter readings to equivalent air columns at mine-air density by multiplying by the ratio determined from the chart. In the method presented here the difference due to elevation is divided by the ratio to obtain the equivalent height of a theoretical, or 50° column. As calculations are taken out only to the nearest foot, the ratio is required only for differences of elevation greater than about 10 to 15 feet.

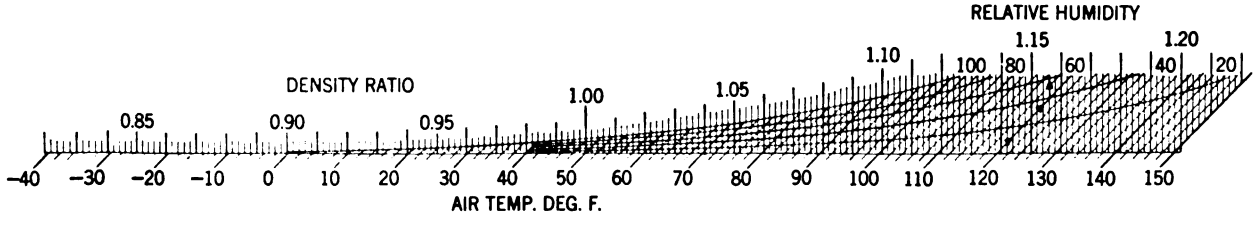

Figure 4. - Ratio of altimeter-scale air density to mine air density. Correction factor for difference of elevation.

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TABLE 1. - Relative humidities for 30.0 inches barometric pressure

Air temperature, t	0.378 x f	Depression of wet-bulb thermometer (t-t')																			
		0,5	1,0	1,5	2,0	2,5	3,0	3,5	4,0	4,5	5,0	5,5	6,0	6,5	7,0	7,5	8,0	8,5	9,0	9,5	10,0	10.5
20	0.039	92	85	77	70	62	55	48	40	33	26	19	12	5								
21	.041	92	85	78	71	63	56	49	42	35	28	21	15	8	1							
22	.043	93	86	78	71	65	58	51	44	37	31	24	17	11	4							
23	.045	93	86	79	72	66	59	52	46	39	33	26	20	14	7	1						
24	.047	93	87	80	73	67	60	54	47	41	35	29	22	16	10	4						
25	.049	94	87	81	74	68	62	55	49	43	37	31	25	19	13	7	1					
26	.051	94	87	81	75	69	63	57	51	45	39	33	27	21	16	10	4					
27	.054	94	88	82	76	70	64	58	52	47	41	35	29	24	18	13	7	2				
28	.057	94	88	82	76	71	65	59	54	48	43	37	32	26	21	15	10	5				
29	.059	94	88	83	77	72	66	60	55	50	44	39	34	28	23	18	13	8	3			
30	.062	94	89	83	78	73	67	62	56	51	46	41	36	31	26	21	16	11	6	1		
31	.065	94	89	84	78	73	68	63	58	52	47	42	37	33	28	23	18	13	8	4		
32	.068	95	89	84	79	74	69	64	59	54	49	44	39	35	30	25	20	16	11	7	2	
33	.071	95	90	85	80	75	70	65	60	56	51	46	41	37	32	27	23	18	14	9	5	0
34	.074	95	90	86	81	76	71	66	62	57	52	48	43	38	34	29	25	21	16	12	8	3
35	.077	95	91	86	81	77	72	67	63	58	54	49	45	40	36	32	27	23	19	14	10	6
36	.080	95	91	86	82	77	73	68	64	60	55	51	46	42	38	34	29	25	21	17	13	9
37	.083	95	91	87	83	78	74	69	65	61	57	53	48	44	40	36	31	27	23	19	15	11
38	.086	96	91	87	83	79	75	70	66	62	58	54	50	46	42	37	33	29	25	21	17	14
39	.090	96	92	87	83	79	75	71	67	63	59	55	51	47	43	39	35	31	27	24	20	16
40	.093	96	92	87	83	79	75	71	68	64	60	56	52	48	45	41	37	33	29	26	22	18
41	.097	96	92	88	84	80	76	72	69	65	61	57	54	50	46	42	39	35	31	28	24	20
42	.101	96	92	88	85	81	77	73	69	65	62	58	55	51	47	44	40	36	33	30	26	23
43	.105	96	92	88	85	81	77	73	70	66	63	59	55	52	48	45	42	38	35	31	28	25
44	.109	96	93	89	85	81	78	74	71	67	63	60	56	53	49	46	43	39	36	33	30	26
45	.113	96	93	89	86	82	78	74	71	67	64	61	57	54	51	47	44	41	38	34	31	28
46	.117	96	93	89	86	82	79	75	72	68	65	61	58	55	52	48	45	42	39	35	32	29
47	.122	96	93	89	86	82	79	75	72	69	66	62	59	56	53	49	46	43	40	37	34	31
48	.126	96	93	90	86	83	79	76	73	69	66	63	60	57	54	50	47	44	41	38	35	32
49	.131	96	93	90	86	83	80	76	73	70	67	64	61	57	54	51	48	45	42	39	36	34
50	.136	96	93	90	87	83	80	77	74	71	67	64	61	58	55	52	49	46	43	41	38	35
51	.141	97	94	90	87	84	81	78	75	71	68	65	62	59	56	53	50	47	45	42	39	36
52	.146	97	94	90	87	84	81	78	75	72	69	66	63	60	57	54	51	49	46	43	40	37
53	.152	97	94	90	87	84	81	78	75	72	69	66	63	61	58	55	52	50	47	44	41	39
54	.158	97	94	91	88	85	82	79	76	73	70	67	64	61	59	56	53	50	48	45	42	40
55	.163	97	94	91	88	85	82	79	76	73	70	68	65	62	59	57	54	51	49	46	43	41
56	.169	97	94	91	88	85	82	79	76	73	71	68	65	63	60	57	55	52	50	47	44	42
57	.176	97	94	91	88	85	82	80	77	74	71	69	66	63	61	58	55	53	50	48	45	43
58	.182	97	94	91	88	85	83	80	77	74	72	69	66	64	61	59	56	54	51	49	46	44
59	.189	97	94	91	89	86	83	80	78	75	72	70	67	65	62	59	57	55	52	49	47	45
60	.196	97	94	91	89	86	83	81	78	75	73	70	68	65	63	60	58	55	53	50	48	46
61	.203	97	94	92	89	86	84	81	78	76	73	71	68	65	63	61	58	56	54	51	49	47
62	.210	97	94	92	89	86	84	81	79	76	74	71	69	66	64	61	59	57	54	52	50	47
63	.217	97	95	92	89	87	84	82	79	77	74	71	69	67	64	62	60	57	55	53	50	48
64	.225	97	95	92	90	87	84	82	79	77	74	72	70	67	65	63	60	58	56	53	51	49
65	.233	97	95	92	90	87	85	82	80	77	75	72	70	68	66	63	61	59	56	54	52	50
66	.241	97	95	92	90	87	85	82	80	78	75	73	71	68	66	64	61	59	57	55	53	51
67	.250	97	95	92	90	87	85	83	80	78	75	73	71	69	66	64	62	60	58	56	53	51
68	.259	97	95	92	90	88	85	83	80	78	76	74	71	69	67	65	62	60	58	56	54	52
69	.263	97	95	93	90	88	85	83	81	79	76	74	72	70	67	65	63	61	59	57	55	53
70	.277	98	95	93	90	88	86	83	81	79	77	74	72	70	68	66	64	61	59	57	55	53
71	.286	98	95	93	90	88	86	84	81	79	77	75	72	70	68	66	64	62	60	58	56	54
72	.296	98	95	93	91	88	86	84	82	79	77	75	73	71	69	67	65	63	61	59	57	55
73	.306	98	95	93	91	88	86	84	82	80	78	75	73	71	69	67	65	63	61	59	57	55
74	.317	98	95	93	91	89	86	84	82	80	78	76	74	71	69	67	65	63	61	60	58	56
75	.328	98	96	93	91	89	86	84	82	80	78	76	74	72	70	68	66	64	62	60	58	56
76	.339	98	96	93	91	89	87	84	82	80	78	76	74	72	70	68	66	64	62	61	59	57
77	.350	98	96	93	91	89	87	85	83	81	79	77	74	72	71	69	67	65	63	61	59	57
78	.362	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	67	65	63	62	60	58
79	.374	98	96	93	91	89	87	85	83	81	79	77	75	73	71	69	68	66	64	62	60	58
80	.387	98	96	94	91	89	87	85	83	81	79	77	75	74	72	70	68	66	64	62	61	59

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The ratio results from dividing the density of 50° F. dry air by the actual mine-air density at the same barometric pressure, that is,

$$\text{Ratio} = \frac{\frac{1.327}{460+50} \times B}{\frac{1.327}{460+t} \times (B-0.378f)} \cdot \qquad (2)$$

Like the relative humidity table, the density-ratio chart can be used with negligible error for altitudes within 2,000 to 3,000 feet of sea level. For differences in elevation in excess of about 200 feet at higher elevations, the ratio should be separately calculated.

Conversion Factors

Pressure differences due to flow are determined in feet of air column and require conversion to inches of water by dividing by a conversion factor; that is, by the number of cubic feet of air column in 5.2 pounds of air, as a pressure of 5.2 pounds per square foot is the equivalent of 1 inch water pressure.

The required factor is thus 5.2 divided by the air density. Where differences are computed, according to general practice, in feet of air column of mine-air density, the latter must be computed for determining the factor. Use of factors based on surface air densities introduces considerable errors. Use of a constant factor based on average mine-air density introduces only minor errors if confined to shallow flat-seam mines.

Conversion factors for converting pressure differences due to flow from feet of air column of altimeter-scale density to inches of water can be readily determined by means of the simple graph shown in figure 3. Thus, for an average altimeter pressure of 391 feet, the conversion factor (from fig. 3) is 67.9 feet.

Similar conversion factors for converting feet of air column of mine-air density to inches of water may be obtained by multiplying the value taken from figure 3 by the appropriate density ratio taken from figure 4. Thus, for 55° F. air with a relative humidity of 71 percent, the density ratio (from fig. 4) is 1.013 and 1.013 times 67.9 is 68.8, the number of feet of air column of mine-air density equal to 1 inch of water. Mine-air densities, in pound per cubic foot, can then be computed by dividing 5.2 by the conversion factors so determined. Dividing 5.2 by 68.8 gives the mine-air density as 0.0756 pound per cubic foot, a result that can be checked through equation (1).

Velocity-Pressure Corrections

Altimeters and barometers determine the absolute static pressure of the atmosphere, whereas flow of air through airways is determined by differences in absolute total pressures. Total pressure is the sum of the absolute static pressure and the velocity pressure. The corrections required to convert determined differences of pressure due to airflow from a static to a total basis could be made in terms of feet of air column, but it is more convenient to use inches of water. The corrections are negligible for velocities below 400 feet per minute (velocity pressure for 400 feet per minute is about 0.01 inch of water) and small in any event (only about 0.25 inch for 2,000 feet per minute velocity). The use of a ratio factor based on average mine-air density is therefore justified.

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Velocity pressures, in inches of water, can be computed by multiplying the values obtained by a simple formula for standard air, of 0.075 pound per cubic foot density, by the ratio of the average underground air-density, d, to 0.075, or

$$V.\ P. = \left(\frac{f.p.m.}{4,008}\right)^2 X \frac{d}{0.075} \cdot \qquad (3)$$

The velocities used for traverse stations should be determined during the pressure survey by means of 1- to 2-minute traverses made in airway sections opposite points where altimeter readings are made, without reference to area of section, and not necessarily at sections in the near vicinity used for quantity-of-flow determinations.

In comparing cumulative pressure differences determined by a survey from mine intake to inlet of an exhaust fan or from discharge of a force fan to discharge to atmosphere, it should be recognized that determined pressure differences include natural-draft pressures as well as fan pressures. Differences found by comparison, with fan inlet total pressure - "water-gage" minus velocity pressure - for an exhaust fan and with fan total pressure - "water-gage" plus velocity pressure - for a force fan, may be due to natural drafts, to errors, or to both.

Survey Calculation Procedures Visualized

The great differences between measured differences in absolute pressures and the pressure differences deduced from measured pressures is shown graphically in figure 5.

Reference to this graph also shows that errors of closure do not reveal errors of measurement of sectional pressure differences, for it can be seen that errors in reading the altimeter, in elevation, and in base correction, for any except end points of a traverse merely result in compensating errors. Too much pressure drop is assigned to one section and too little, and of the same amount, to the adjacent section. Only repeated surveys and accurate elevations give absolute checks on the accuracy of the work.

Certain pressure differences can be checked against water-gage readings on doors and on stoppings. Often, these are the only checks possible.

Pressure Loss at Regulators

In the course of a pressure survey pressure differences on all regulators should be measured with a U-tube water gage, or other type of differential-pressure instrument. The pressure difference on the stopping in which the regulator opening exists is not, however, the pressure loss occasioned by the regulator, although it approximates it in practice. Some conversion of velocity pressure to static pressure occurs downstream of the regulator. An approximately inverse linear relation exists between the actual pressure loss and the measured pressure difference. The relation is shown in figure 6.

Calculation Form

Use of a form facilitates computations. The form now used by the Mine Ventilation Section of the Bureau of Mines is shown in figure 7, on which the results of a survey of a small slope mine have been entered. Column numbers have been added for easy identification. No column is shown for ambient temperature correction to altimeter readings, as the temperature corrections on the instruments used are negligibly small.

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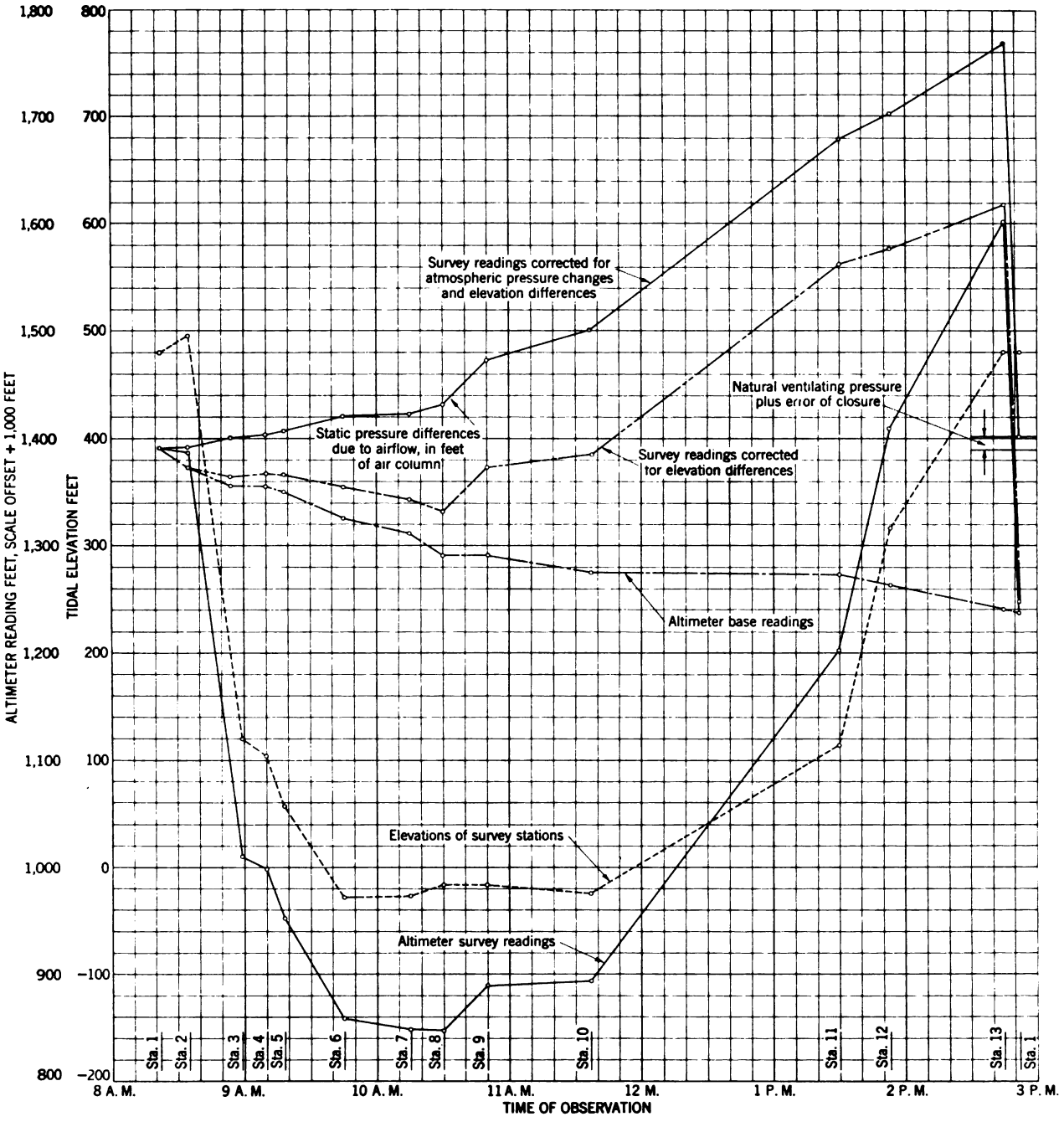

Figure 5. - Graph showing deduction of pressure differences from altimeter survey data.

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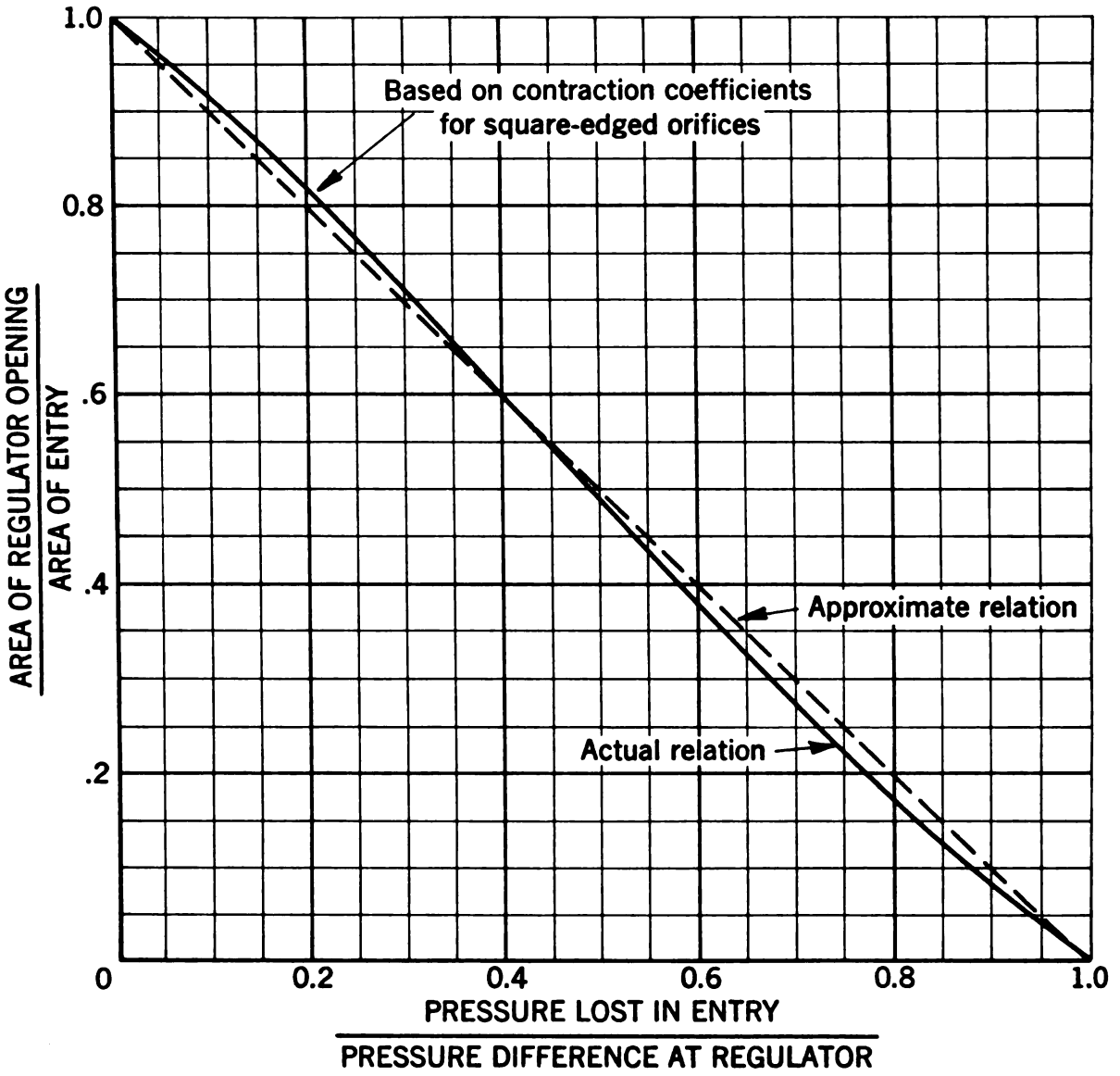

Figure 6. - Chart for determining pressure losses at regulators from measured pressure differences.

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ALTIMETER VENTILATION PRESSURE SURVEY

Sheet No. —

Company X
Mine No. 2
Traverse Pressure survey made concurrent with quantity survey

Date 11-15-56
Observers D.S.K., E.J.H., M.D. and W.M.B. (base)

Calculated by E.J.H. Date 11-20-56
Checked by D.S.K. Date 11-21-56
Average air densities; surface 0.0755, fan inlet 0.0727

Observations									Data					Calculations										Remarks
Sta.	Location	I R	Time	Alt. rdg. ft.	Temp. Wet °F.	Temp. Dry °F.	Rel. hum. %	Vel. f.p.m.	Vel. press. ins. w.g.	Base alt. rdg. ft.	Elev. ft.	Diff. elev. ft.	Den. ratio	Alt. diff. ft.	Base corr. ft.	Elev. corr. ft.	Diff. static press. ft.	Avg. alt. rdg. ft.	Feet air per inch w.g.	Diff. static press. ins. w.g.	Diff. vel. press. ins. w.g.	Diff. total press. ins. w.g.	Total press. ins. w.g.	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)
1	Surface at fan house	Base	8:22	1391	49	53	75	0	0	1391	482													
2	Rock slope portal	I	8:35	1387	50	53	81	0	0	1373	496	+14		-4	+18	-14	0							Midpoint of slope
3	Rock slope bottom	I	8:59	1010	57	64	65	475	0.014	1355	120	-376	1.022	-377	+18	+368	+9	1198	67.4	-0.133	+0.014	-0.119	-0.119	54-60; 1192
4	Main N. by sta 1925	I	9:10	998	57	65	61	450	0.013	1355	104	-16	1.034	-12	0	+15	+3	1004	66.9	-0.045	-0.001	-0.046	-0.165	
5	Main N by sta 2700	I	9:18	952	60	65	75	390	0.010	1350	57	-47	1.034	-46	+5	+45	+4	975	66.8	-0.060	-0.003	-0.063	-0.228	3.0" w.g. 1-R at sta. 5
6	Junction main N & main E.	I	9:45	859	62	65	85	360	0.010	1325	-28	-85	1.035	-93	+25	+82	+14	906	66.7	-0.210	0	-0.210	-0.438	15" w.g. 1-R out bye 6
7	Main E opposite 2 N.	I	10:15	848	62	64	90	230	*	1311	-27	+1		-11	+14	-1	+2	853	66.6	-0.030	-0.010	-0.040	-0.478	
8	Main E opposite 3 N.	I	10:30	847	63	65	90	130	*	1291	-17	+10		-1	+20	-10	+9	848	66.5	-0.135	0	-0.135	-0.613	
9	Main E. return at 3 N.	R	10:50	889	70	72	91	475	0.014	1291	-16	+1		+42	0	-1	+41	868	66.5	-0.616	+0.014	-0.602	-1.215	
10	Main E. return at M N.	R	11:37	894	69	70	95	350	0.010	1276	-24	-8		+5	+15	+8	+28	898	66.6	-0.420	-0.004	-0.424	-1.639	
11	Main N. at old coal slp.	R	1:30	1203	70	70	100	220	*	1274	114	+138	1.048	+309	+2	-132	+179	1048	67.0	-2.672	-0.010	-2.682	-4.321	
12	Bottom upcast shaft	R	1:53	1410	70	70	100	880	0.048	1264	317	+203	1.049	+207	+10	-193	+24	1307	67.7	-0.355	+0.048	-0.307	-4.628	
13	Top up sh. - fan inlet	R	2:45	1610	68	68	100	1590	0.158	1241	482	+165	1.046	+200	+23	-158	+65	1510	68.2	-0.953	+0.110	-0.843	-5.471	
1	Surface at fan house	Base	2:52	1238	43	50	55	0	0	1239	482	0		-372	+2	0	-370	1424	67.9	+5.450	-0.158	+5.292	-0.179	NVP + error of closure
																								NVP calc. as -0.18
																								SP at fan inlet 5.5" w.g.
			11-16																					
2	Top of slope	I	8:50	909	31	37	48			Simul	496													
3	Bottom of slope	I	8:50	539	47	54	59	475	0.014	rdgs	120	-376	0.993	-370		+379	+9	724	66.2	-0.136	+0.014	-0.122		
12	Bottom of shaft	R	9:25	1041	69	69	100	880	0.048	Simul.	317													
13	Top of shaft	R	9:25	1264	69	69	100	1590	0.158	rdgs.	482	+165	1.046	+223		-158	+65	1153	67.3	-0.966	+0.110	-0.856		
		* Negligible - Taken as 0 in calculations																						

Figure 7. - Calculation sheet for ventilation pressure survey of a small slope mine.

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The data to be entered in columns 1 through 13 are evident from the preceding discussion. In column 3, "I" designates stations on intake-air currents and "R" stations on return-air currents. Relative humidities for column 8 can be found from table 1 or similar tables. Base altimeter readings for column 11 for the time the altimeter was read can be interpolated from readings made at the base station but preferably are taken from a plotted graph of the readings of the base instrument.

The density correction factor for column 14 can be obtained from figure 4, using average figures for temperature and relative humidity from columns 7 and 8. As previously explained, this factor is actually the ratio of altimeter-scale density to mine-air density. Division of the difference in elevation by this factor converts feet of mine-air column to equivalent feet of theoretical air column corresponding to the altimeter scale.

Column 15 is the difference in altimeter readings at successive pairs of stations, + (plus) for a higher reading at the second station of the pair and - (minus) for a lower reading. It is actually the difference between the absolute static pressures at the stations in feet of air column of altimeter-scale density. It represents the difference due to the combined effects of flow, change in atmospheric pressure, and difference in elevation.

For column 16 the differences between the successive figures of column 11 are obtained, plus or minus, but they are entered in the column with the sign reversed, as plus differences increase the altimeter difference over that occasioned by airflow alone and minus differences decrease the altimeter difference over what it would have been had there been no change in the base atmospheric pressure.

For column 17 the differences in elevation, plus or minus, in column 13 are divided by the density correction factor of column 14, but the results of these divisions are entered in column 17 with the sign reversed, as an increase in elevation produces an increase in altimeter difference that is not due to flow and so must be subtracted. Decreases in elevation must, for a simular reason, be added to altimeter differences.

The algebraic sum of the figures in columns 15, 16, and 17 is entered in column 18 to give the difference in static pressure due to flow between the two successive stations in feet of air column of altimeter-scale density.

The average altimeter reading for pairs of successive stations is entered in column 19. This value is used in entering the graph of figure 3, from which the conversion factor, or number of feet of air column equivalent to 1 inch of water pressure, is determined and entered in column 20.

For column 21 the number of feet of air column, plus or minus, of column 18 is divided by the conversion factor from column 20 and entered in column 21 with the sign reversed, as the altimeter scale is really an inverted pressure scale. The higher the readings, the lower the pressure, and vice versa. This column gives the difference in absolute static pressure in inches of water between successive stations due to flow; that is, the same difference as would be determined for the same flow conditions between two points at the same elevation and at times when there was no change in the atmospheric pressure.

Flow is produced by differences in absolute total pressures, and absolute total pressure is the sum of the absolute static pressure and the velocity pressure. Differences between successive stations, plus or minus, from column 10 are entered in colum

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22; and the algebraic sums of the figures in columns 20 and 22 are entered in column 23. The sketches in figure 8 show how this procedure holds good, regardless of whether the survey stations proceed with or against the direction of flow.

Cumulative total pressure differences from the base station, paying particular regard to sign, are entered in column 24.

Column 25 is reserved for remarks, particularly as regards data on U-tube water-gage readings obtained on doors and stoppings and as regards anything of any nature noted that might affect the accuracy of survey results.

Where the survey involves a closed pressure loop, starting and finishing at the same point then, in the absence of natural draft pressures, the final pressure should be 0, and the closeness of the result to 0 is indicative of the accuracy of the calculations. As computations are carried out only to the nearest foot, or to about 0.014 inch of water, a final result of 3 to 4 feet (or 0.04 to 0.06 inch of water), representing the error of closure, is to be expected.

Although a small error of closure indicates a high degree of overall accuracy, many errors due to incorrect elevations, incorrect altimeter readings, and incorrect velocity-pressure differences result in compensating errors. The loss determined for one section is too high or too low, while that determined for an adjoining section is correspondingly too low or too high. Absolute accuracy can therefore be gaged only by comparing the results of independent check surveys; it depends on the accuracy of elevations and of the calibrations of the instruments used.

APPLICATION OF SURVEY DATA

Although the pressure-loss data resulting from a survey can be used with data resulting from a concurrent quantity survey to develop resistance factors and power-loss data useful in economic analyses of improvement procedures, the best way to highlight sections causing exceptionally high pressure losses is to construct a pressure gradient such as is shown in figure 9, in which the steep gradients on the return side indicate plainly where most of the resistance to flow is located. Total pressures from column 24 are plotted against distance of airflow travel. Sections of exceptionally high resistance show up as sections having steep gradients, indicating where corrective measures can accomplish the most toward improving the ventilating system. How the corrective measures can be made can be determined by inspection and engineering studies to determine the economy of the methods considered.

Inefficient ventilation and excess power cost are due largely to leakage but often are due to obstructed and fallen aircourses, an inadequate number of aircourses, an inadequate number or size of overcasts in multiple-entry systems, and excessive distances traveled by the flow. Often splits are poorly balanced or not equalized by the proper location of overcasts.

The application of analyses based on pressure and quantity data can remove much of the guesswork from ventilation planning and eliminate many of the expensive trial-and-error methods of procedure now practiced. Proper application of survey data can result in larger quantities, better distribution, and lower power costs.

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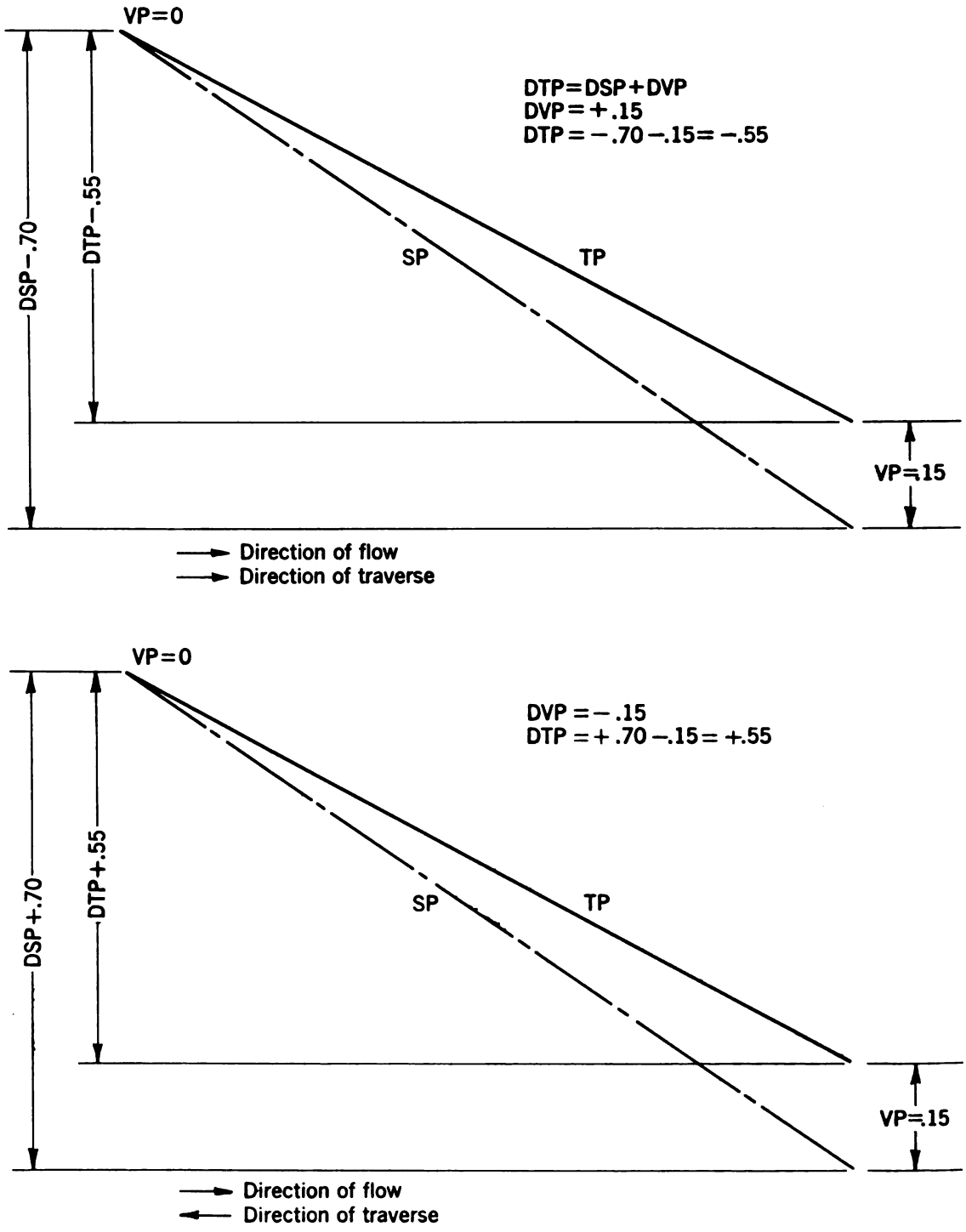

Figure 8. - Sketches showing velocity pressure corrections.

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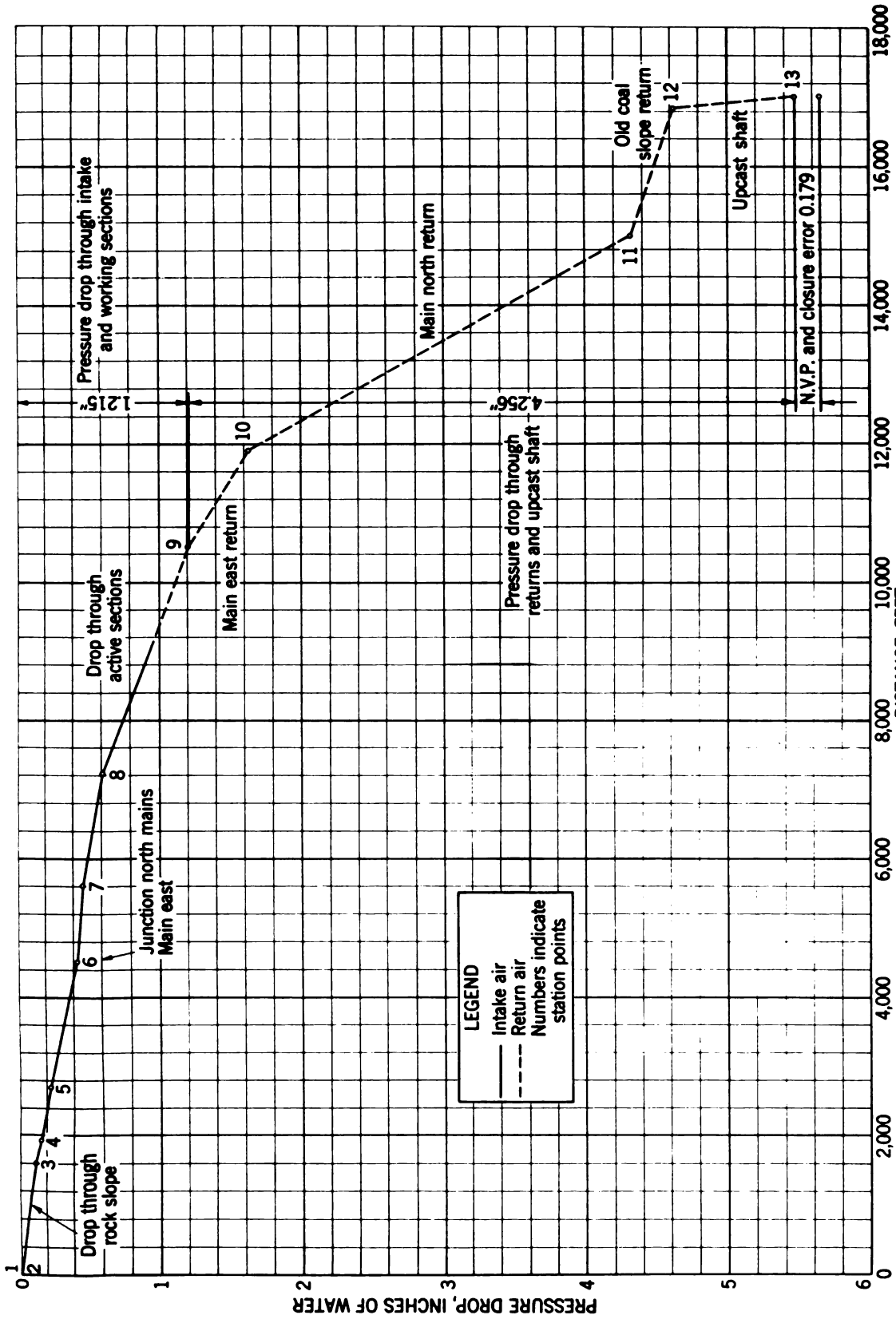

Figure 9. - Ventilation pressure gradient for a small slope mine.

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